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Verification and Validation of ALEGRA-MHD using 2D, Radiation MHD Modeling of Z Liner Implosions

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Abstract

Wire array implosions like those on the Sandia Z machine are problems where three-dimensional MHD effects and radiation transport play a significant role. Therefore, MHD modeling of these implosions requires a 3D radiation MHD code. Sandia is developing such a code, ALEGRA-MHD, for work on simulating full wire arrays. Given the complexity of 3D radiation MHD simulations, verification and validation are critical. By modeling simplified 2D radiation MHD liner implosions, results from ALEGRA-MHD can be compared not only to data but to results from other 2D radiation MHD codes. Comparisons of the kinetic, magnetic and radiated energy as a function of time for the various codes are shown.

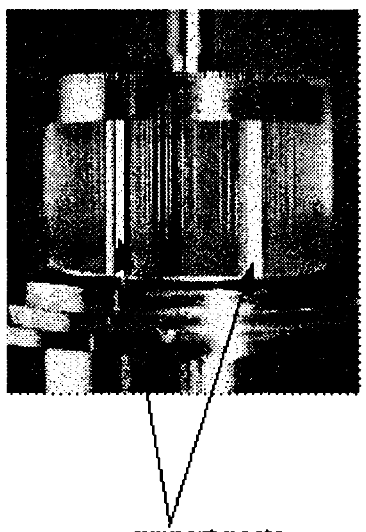
Conclusions

- Sandia is developing a multi-physics code called ALEGRA-MHD with a combination of features that make it unique and thereby make careful code verification and validation necessary:
  - 2D/3D and parallel
  - multi-material (including void) with radiation
  - unstructured grids
  - arbitrary Lagrangian-Eulerian

- We have simulated 2D, R-Z liner implosions because of the theory and results of other MHD simulations (verification) and data (validation) available:
  - We test the magnetic push, the Rayleigh-Taylor growth, the energy conservation in shock heating, and the radiation emission model against analytic results.
  - We compare the kinetic and radiated energy as a function of time for Z Shot 360 to results from another Rad-MHD code.
  - We compare peak power magnitude and timing to Z data.

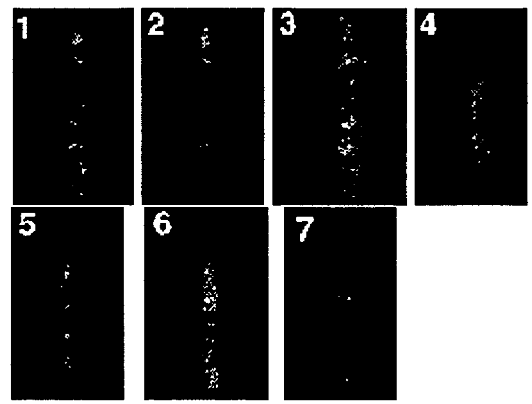
Modeling the Sandia Z machine requires a 3D MHD code capable of radiation transport

The initial geometry of the wire array is inherently 3D.



240-wire array
load for Z machine

Radiation production and transport is an integral part of a Z implosion.



X-ray pinhole images of
imploding wire array plasma

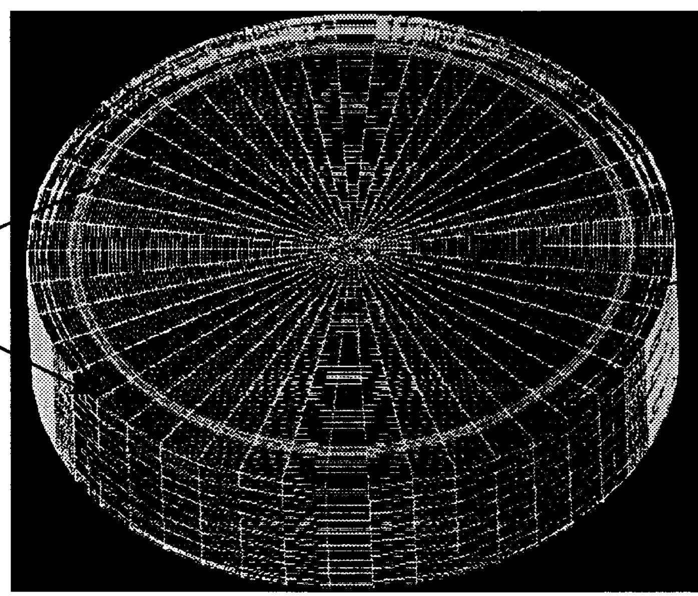
- Verification and validation of such a code is a necessary first step.

ALEGRA is Sandia's parallel, 3D framework for MHD

•ALEGRA is an object-oriented framework in C++. Many codes (e.g. ALEGRA-MHD) hang off this framework.

•ALEGRA-MHD is a 2D/3D, parallel, finite elements code. It is a Lagrangian code with an Eulerian remap option.

•It handles multiple materials, including void, on unstructured grids and has a variety of radiation options, including emission and diffusion.



void

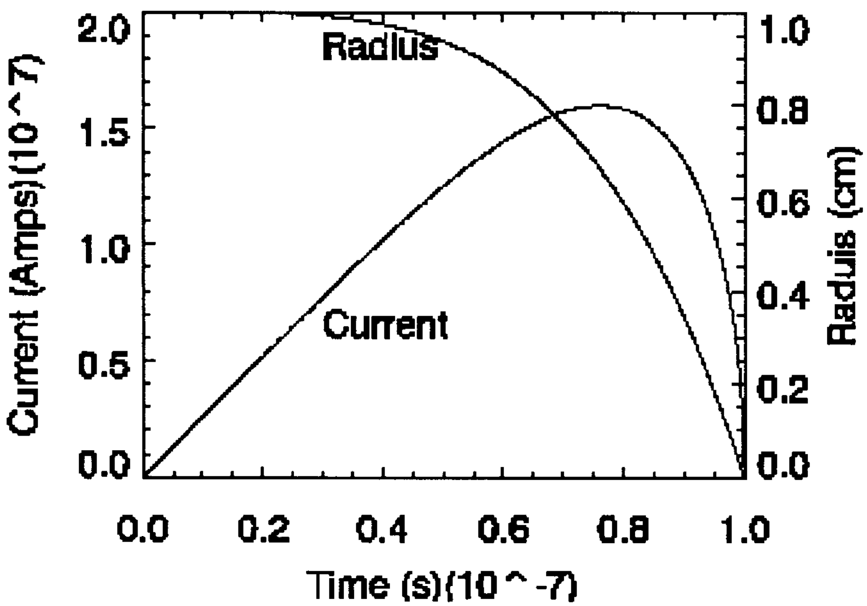
plasma

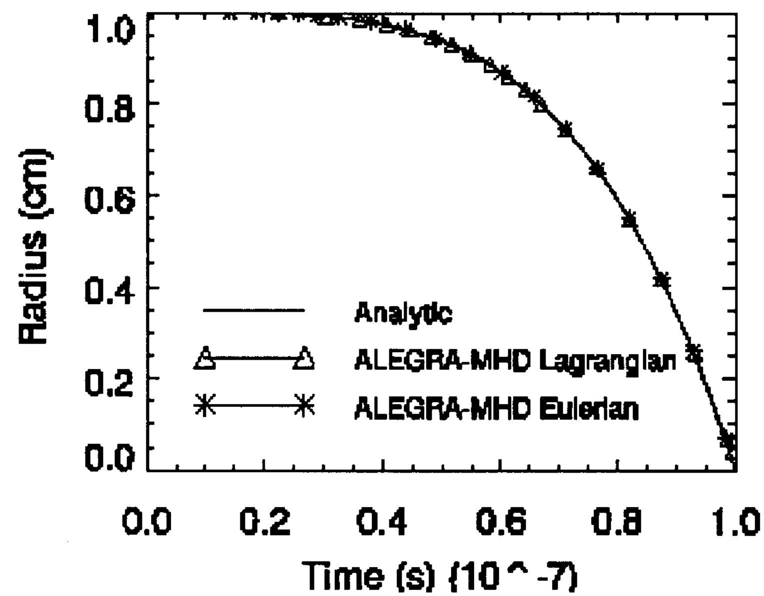
Liner implosion physics has four distinct parts: magnetic push, Rayleigh-Taylor growth, shock heating and radiation production

- We test each of these physics algorithms separately against an analytic result:
  - The magnetic push is tested by tracking liner radius as a function of time for a current pulse which gives a known acceleration
  - The Rayleigh-Taylor growth is tested by measuring the growth of a single RT mode for which the growth rate is known analytically
  - The shock heating is tested by monitoring energy conservation for the cylindrical Noh problem
  - The radiation emission model is tested by measuring the cooling rate of a hot gas into vacuum for which the temperature as a function of time is known analytically

The radius as a function of time for a 1D liner agrees with analytic results to within expected error, verifying the JxB force algorithm

•For this problem, a current is applied [$I \sim (t^2(1-t^4))^{1/2}$] to a 1D liner which yields a known radius as a function of time [$r \sim (1-t^4)$].





•Both Lagrangian and Eulerian results for this problem agree to less than a percent, verifying the magnetic pressure in ALEGRA-MHD is correct.

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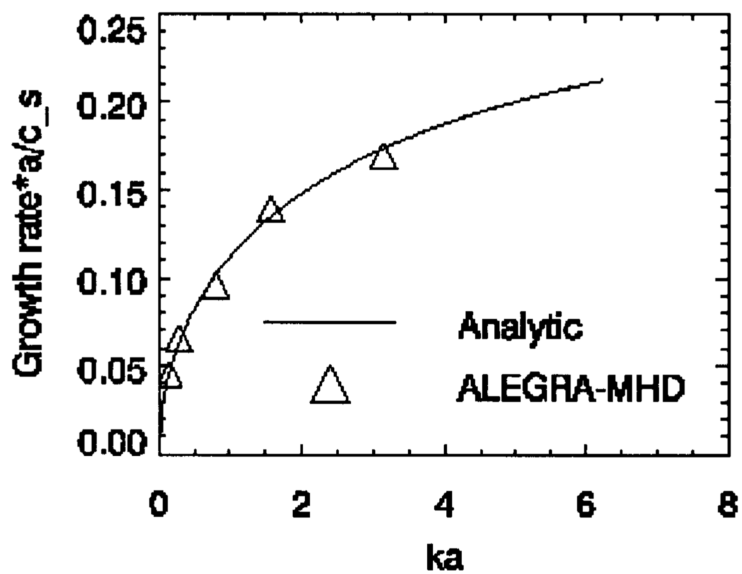
The Rayleigh-Taylor growth rate agrees to within a few % with analytic results

•For this problem, a current is applied [$I \sim (1-t^2)^{1/2}$] to a 2D liner with a single RT mode seeded that gives constant acceleration, g. The growth rate for such a current is known analytically: [$\gamma = (kg/(1+(ka)^2)^{1/2}$], where a is the liner thickness.



•Lagrangian results for this problem agree to within a few percent for relevant values of ka, as seen above. The Eulerian results require more resolution (see B. Oliver, DO2.010), but also agree with theory.

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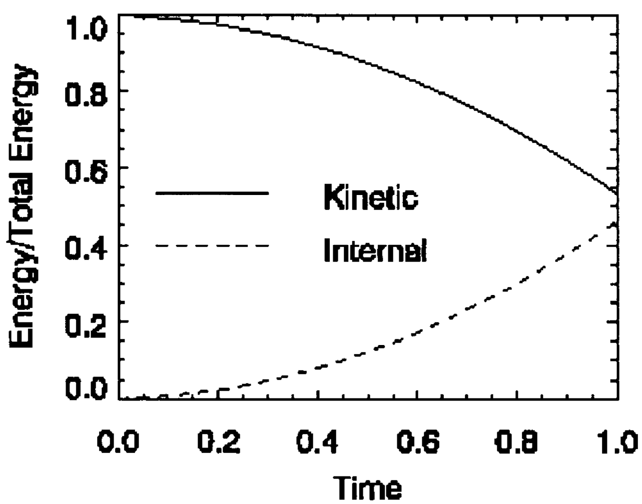
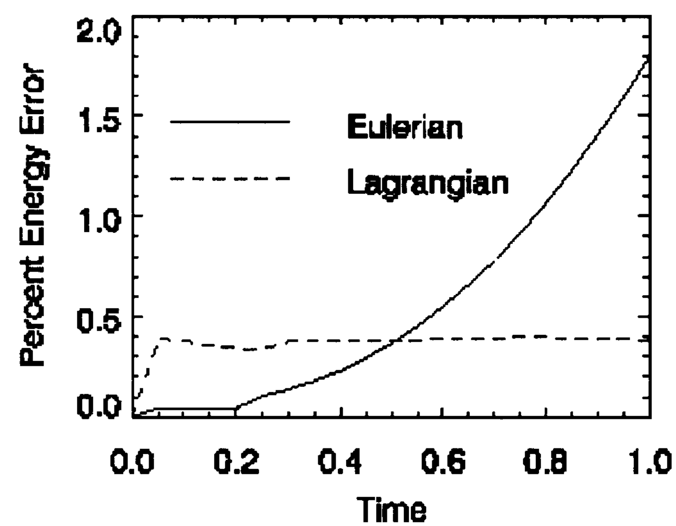
The shock heating of the plasma is tested using the cylindrical Noh problem

•For this problem, a liner of cold plasma is started on-axis with a velocity radially inward. Energy conservation is measured as the energy is converted from kinetic to internal.





•The Lagrangian version of the code conserves energy to less than a percent in the time half of the energy is converted from kinetic to potential. The Eulerian code conserves energy to within a few percent.

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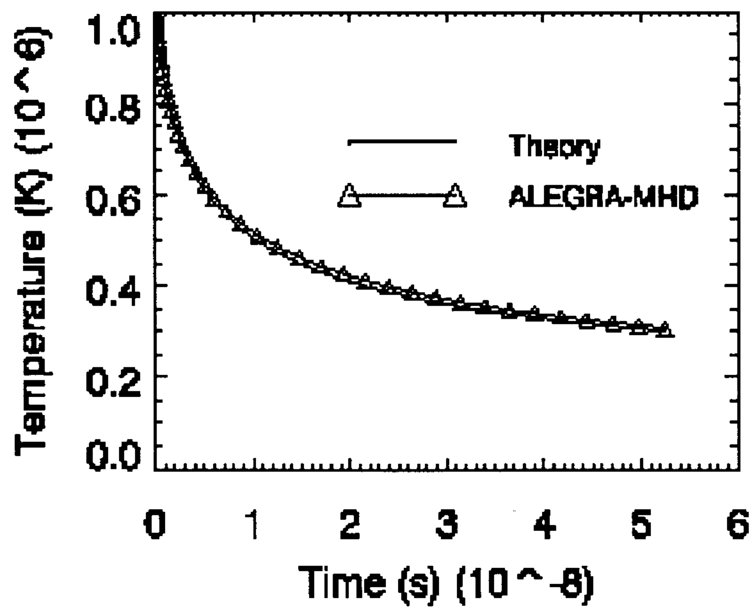
The cooling of a hot gas via the emission of radiation reproduces the analytic temperature to within a few percent

•For this problem, a hot plasma cools by radiation into vacuum. The temperature as a function of time is known [$T \sim (1+t)^{-1/3}$], assuming blackbody emission.



•The temperature as a function of time from ALEGRA-MHD agrees with theory to within a few percent in the time it takes the temperature to cool to just below half its initial value.

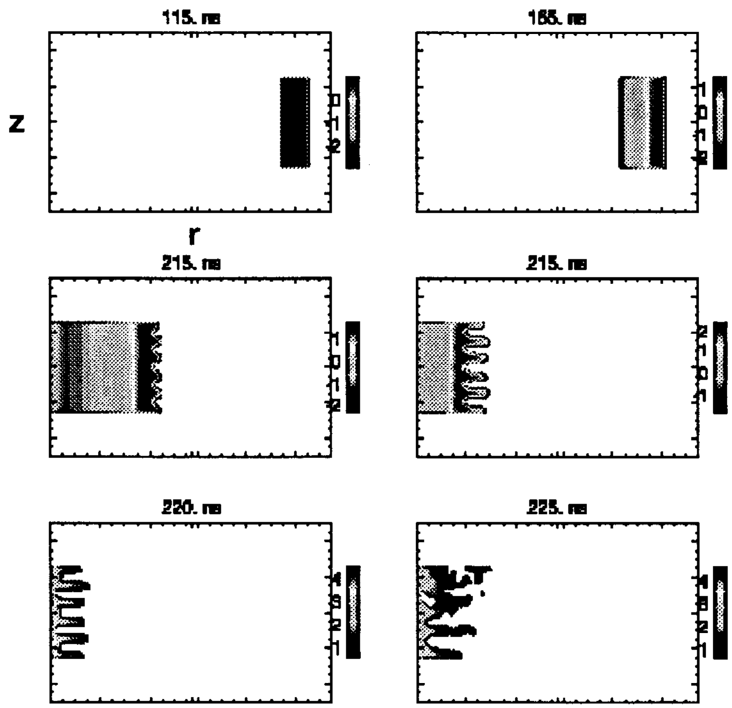
To compare with other codes and data, we modeled Z Shot 360

- Z Shot 360 is a 240-wire, 20-mm Tungsten wire array shot with a peak power of x.x TW at x.x ns. We can compare the peak power and timing with ALEGRA-MHD.

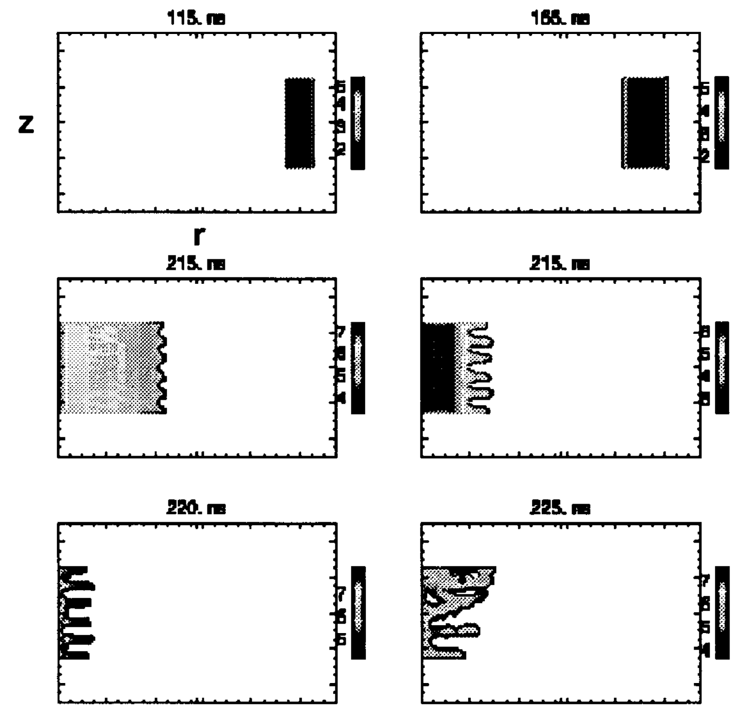
- This shot has also been modeled with another Rad-MHD code. We can compare the energies as a function of time between the two codes.

The density and temperature contours for Z360 show RT growth and heating

Density contours (kg/m^3)



Temperature contours (K)



- The low-density blow-off arrives 10ns before strike, creating a simulation which is effectively filled with plasma. The maximum temperature in the liner is around 10eV.

The energy and power for Z360 can be compared with other codes and data

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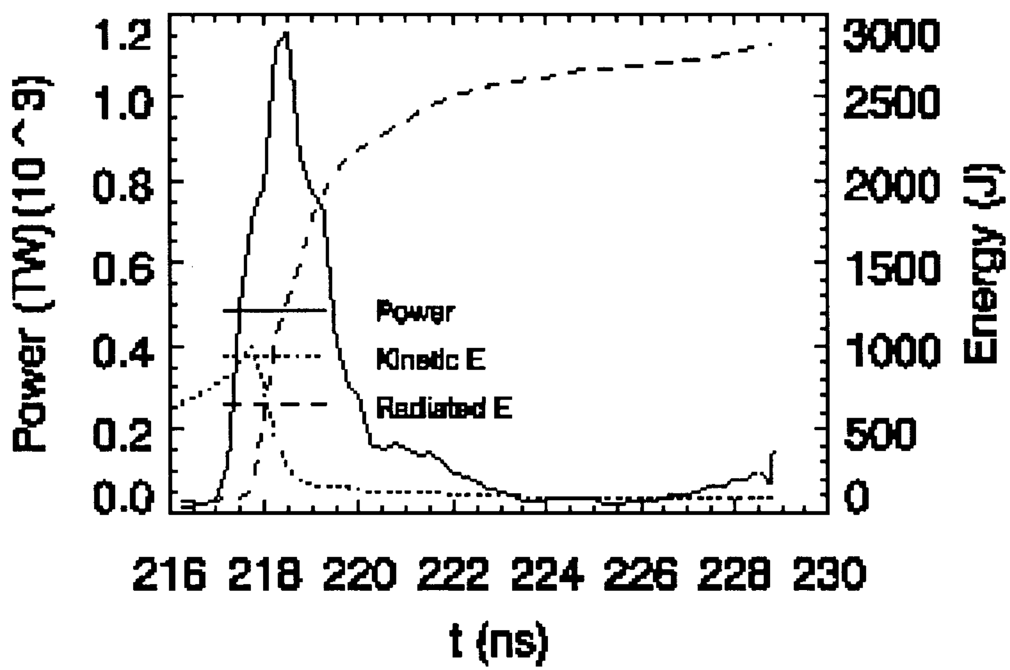

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